



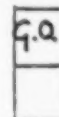
**ontario hydro
research division**

EXECUTIVE SUMMARY

THE DEVELOPMENT AND TESTING OF
ATMOSPHERIC TRACER TECHNIQUES - A PILOT STUDY

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Methods for carrying out short-range atmospheric tracer dispersion experiments have been successfully developed and tested at Wesleyville. Sulfur hexafluoride gas, which is nontoxic, colourless, odourless and readily detected at very low concentrations was released from a location of interest and detected downwind using an array of sequential samplers. At the same time comprehensive meteorological measurements were made to interpret tracer concentration patterns. These techniques provide a potential means of obtaining direct, site-specific information regarding the ways in which the atmosphere disperses emissions from Ontario Hydro's operations. Such information may be useful for validating dispersion models used for regulatory or operational purposes, or for gaining information on how the particular characteristics of a site affect dispersion.



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ontario hydro
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G.L. Ogram
G.C. Edwards

A tracer tracking technique, based on the release and detection of sulfur hexafluoride (SF_6) gas, has been developed for studies of short-range atmospheric dispersion. The system was tested by means of a full-scale pilot study carried out at Wesleyville, a lakeshore site, similar to the sites at which Ontario Hydro's major electricity generating facilities are located. This report documents the methods developed and uses the results of the pilot study to illustrate how useful information may be obtained. It is suggested that these techniques would be particularly useful for comprehensive studies of short range dispersion at Ontario Hydro's nuclear generating stations.

1.0 INTRODUCTION

Releasing small amounts of tracer gas to the atmosphere and tracking its movement downwind is an effective and well-established method of obtaining direct information regarding atmospheric dispersion. Potential applications of tracer techniques that are of interest to the electric utility industry include:

- (i) validation and/or optimization of models used to predict the pathways of atmospheric emissions, for regulatory or operational purposes and site assessment,
- (ii) quantitative investigation of the particular features of downwind concentration patterns that arise due to site specific factors such as building wake, local terrain and lakeshore siting or as a result of particular meteorological conditions.

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It has become increasingly recognized that many dispersion models used for air pollution analysis and control policy are not sufficiently well validated, considering the widespread regulatory and operational use these models receive. For example, problems arise when model predictions are extended to conditions (eg, downwind distances, site locations, meteorological conditions) considerably different from the limited data set on which the models were based (Brown and Landergan, 1983; Vanderborcht and Kretzschmar, 1984). In addition, even in the case of a single model, different methods of providing empirical input parameters may give contradictory results depending on the site locations and conditions under which they are used. An important example of this is the choice of Pasquill stability class which is a necessary input to many commonly used Gaussian models. Available methods such as those based on incoming solar radiation and wind speed (STAR), vertical temperature gradient and fluctuations in wind direction may often give very different results (Kretzschmar and Mertens, 1984; Sedifian and Bennet, 1980; Miller and Little, 1980; Portelli, 1976).

These difficulties may be largely overcome by tracer studies which allow the testing of model performance on a site specific basis and provide a means of optimizing or tuning models for a particular application.

Many tracer studies have been carried out for or by utilities elsewhere (eg EPRI 1979, 1980, 1983; Doolan et al, 1984; Graham and Hovind, 1980; Sagendorf et al, 1980; Johnson et al, 1983; Draxler, 1984). In the case of short-range transport (distances less than a few tens of kilometres), phenomena that have been studied include:

- dispersion from near-ground level and tall stack releases in uniform and complex (valley, hilly) terrain,
- dispersion from tall stacks in lakeshore environments,
- dispersion of releases from buildings.

To some extent it is possible to extend the findings of these studies to other sites. However, dispersion phenomena associated with a particular site or building configuration may need to be investigated in situ. Because of this, the Atmospheric Research Section has recommended the use of tracer techniques to generate information regarding actual atmospheric flow patterns and the dilution of emissions at Ontario Hydro's generating station sites (Glass, 1977; Kalvins, 1983, 1984a,b; Ogram and Melo, 1984; Ogram and Edwards, 1984).

This report describes a pilot tracer study that was carried out at Wesleyville. This site was chosen for the test as its lakeshore siting is similar to that of Ontario Hydro's major

operating generating stations. It is well known that lakeshore environments exhibit a complex dispersion climatology because of land/lake effects such as the lake breeze (Misra 1980). For simplicity, it was also decided to restrict experimental considerations to the treatment of short-range dispersion. The purposes of the study were therefore to:

- (i) develop, test and evaluate systems for carrying out short-range atmospheric tracer dispersion experiments,
- (ii) gain experience in carrying out such experiments.

The following sections document the development of procedures and the study results. Recommendations are made regarding possible applications of these methods.

2.0 METHODS

There are two central aspects to a tracer study of atmospheric dispersion. These are:

- (1) obtaining sufficient information regarding the downwind concentration patterns of the released tracer,
- (2) obtaining sufficient meteorological measurements to allow interpretation of observed concentration patterns and the testing of dispersion models.

The procedures developed to meet these needs are described in the following. A description of the site and an overview of the study design are given first.

2.1 Site Description

Four tracer releases were carried out at Wesleyville during October and November, 1984. Wesleyville is located on the north shore of Lake Ontario (latitude 43° 56' N, longitude 70° 28' W).

Releases were carried out near ground level (1.5 m). Plume concentrations were measured 1 m above the surface, along lateral arcs extended to intersect the plume at distances of from 1 to 3 km downwind.

An aerial photograph of the study area is shown in Figure 1. The terrain is gently rolling and rural, consisting mostly of farmers' fields and treed areas. Indicated in the figure are the tracer release points, sampling arcs and the locations of the meteorological instruments. Release point 1 was -320 m

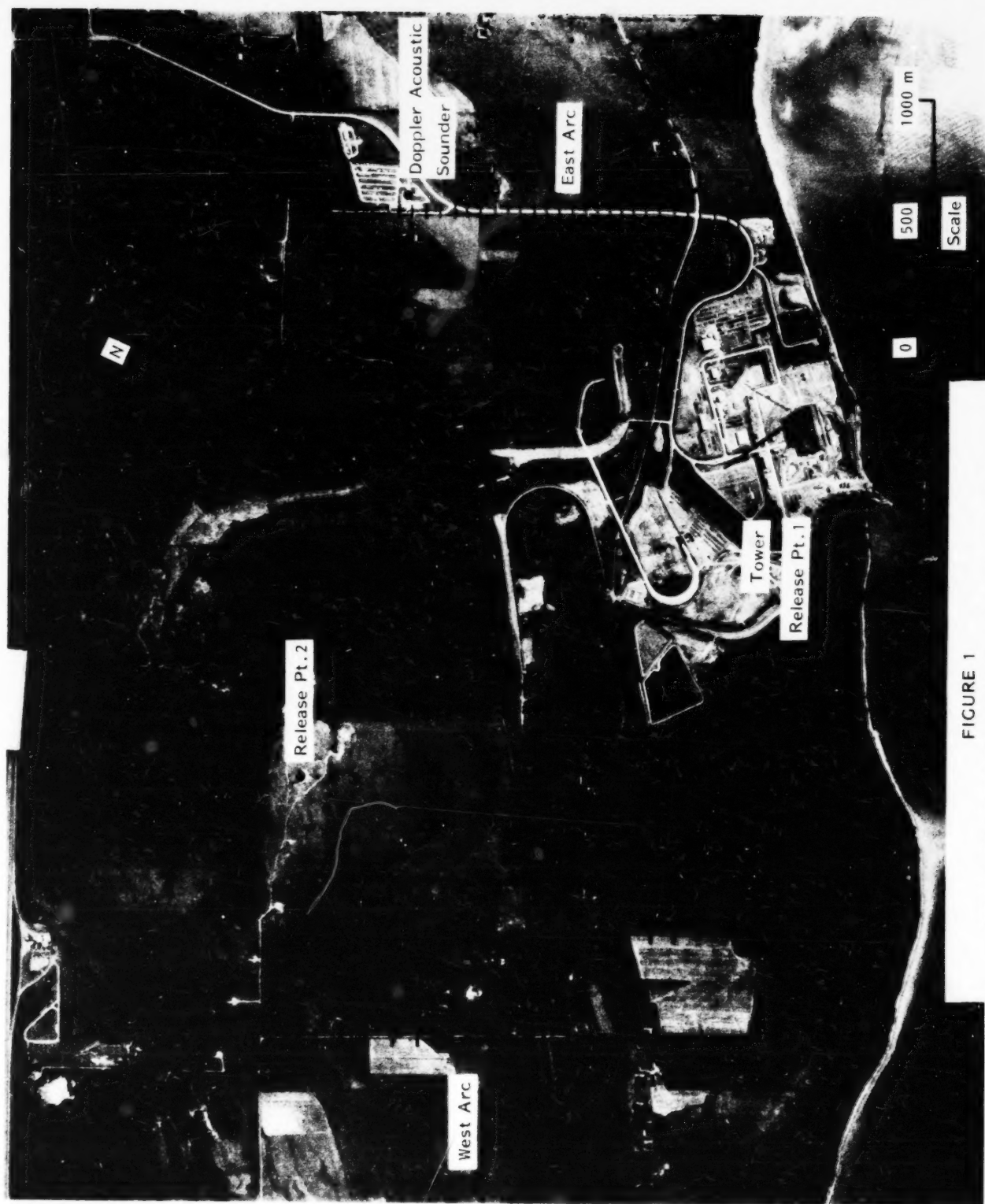


FIGURE 1
 AERIAL PHOTOGRAPH OF THE WESLEYVILLE SITE
 SHOWING POSITIONS OF RELEASE POINTS, METEOROLOGICAL
 EQUIPMENT AND PREMARKED SAMPLING ARRAYS

from the shoreline and ~200 m northwest of the partly completed Wesleyville TGS building. Release point 2 was ~2.3 km from the shoreline and located in an open field.

The sampling arcs were chosen so as to intersect the prevailing wind directions expected at that time of year (easterly and southwesterly). For convenience, potential sampler locations were restricted to existing road systems. The east and west arcs intercepted sectors subtending angles of 45° and 60° from release point 1, respectively. During the course of the study the second release point (release point 2) was selected to allow studies to be carried out under a wider range of wind directions.

Potential sampler locations were premarked along two roads, both running approximately north-south, one ~1 km east of the meteorological tower site and another ~2 km west of the site. Labelled stakes were spaced 50 m apart on the east array and 100 m apart on the west array. This allowed an angular resolution of about 2° from release point 1 which enabled the plume profile to be resolved with sufficient accuracy for centreline concentrations to be accurately determined over a range of stability conditions. With 20 samplers available for deployment, an arc of approximately 40° could be covered.

2.2 Tracer-Release System

Sulfur hexafluoride (SF_6) was used as a tracer gas. It is nontoxic, easily detected at low concentrations and has been commonly used as a tracer. Its usefulness is primarily limited to the short-range (less than a few tens of km) because of the relatively high ambient background arising from its widespread industrial use. The release rate required depends on the SF_6 detection sensitivity (or background concentration if sufficiently high) and the plume dilution factor (Dabbert and Dietz, 1983; Kalvins, 1984b). The latter in turn depends on atmospheric stability and wind speed. For the present study, where sampling distances were <3 km, release rates of <2.5 kg h⁻¹ were found to be adequate for unstable conditions. The background concentration was always below the detection limit.

A simple release system based on a single SF_6 cylinder, regulator and flow controller (Tylan) was found to be sufficient to maintain these release rates. Higher release rates may require the use of more than one SF_6 cylinder and a heated outlet manifold (Dabbert & Dietz, 1983; Kalvins, 1984a). The output of the flow meter was monitored continuously on a chart recorder. The SF_6 cylinder was also weighed before and after each release as a check on the total amount released.

2.3 Tracer Sampling

Lateral Profile

Twenty sequential samplers (Environmental Measurements Inc. Air Quality Sampler II) were used to measure downwind concentrations (Handy, 1985a). Before commencing an experiment, these samplers were deployed along an arc chosen, on the basis of the anticipated wind direction, so as to intersect the plume. A series of sequential, 1 hour average samples (usually three or four) was collected for each experiment. After each experiment the samplers were collected and the sampling bags (Tedlar) removed, sealed and returned to the laboratory for analysis. Air samples were analyzed by electron capture gas chromatography (Handy, 1985b). The minimum detectable concentration was 10 pptv¹. At concentrations of 100 pptv measurements were reproducible within 5%.

Vertical Profile

The direct sampling of vertical profiles at downwind distances of a few km presents a difficult problem as typical plume heights at these distances are of the order of tens to hundreds of meters. A method that has been used in the past with some success involves a balloon supported series of sampling platforms (Davis et al, 1981). The system developed in the present study consisted of a kite-balloon (AIR TS-1BR-3) of 3.2 kg payload capability which supported sampling packages, of our own design, at typically 50 m intervals up to a height of 200 to 300 m (Ogram, 1985). Each sampling platform contained a small air pump with power supply and a radio operated on/off switch.

The system was operated successfully and with some practice could be raised or lowered in about 30 minutes. However, two problems were identified in the operation of the system: (1) it could only be readily operated in low winds (less than 5 m s⁻¹) and (2) it was difficult (especially with low wind speeds) to predict the plume direction accurately enough to ensure that the samplers intercepted the plume.

2.4 Meteorological Instrumentation

A network of meteorological instrumentation, designed on the basis of instruments available within the Section, was used to characterize atmospheric dispersion conditions during each

¹ Parts per trillion (10¹²) by volume.

experiment. The planned instrumentation and the resulting measured and derived meteorological parameters are detailed in Table I. In summary these included:

- (i) Meteorological tower located near the first release site to monitor wind and temperature near the surface.
- (ii) Net radiometer at tower site.
- (iii) Doppler acoustic sounder to provide vertical profiles of winds and thermal structure at about 2 km inland. It was sited near the east sampler array.
- (iv) Monostatic acoustic sounder to monitor atmospheric thermal structure further inland (-5 km from shoreline).

Instrument locations are indicated in Figure 1.

In addition to this, pilot balloon (PIBAL) or PIBAL/minisonde flights were flown hourly at the meteorological tower site for the duration of each experiment. When personnel were available dual theodolites were used. Surface meteorological observations of wind, temperature and relative humidity were also made hourly during each experiment along with visual observations of cloud cover. Surface observations were taken 5 to 10 minutes prior to each PIBAL release.

Apart from giving standard information such as wind direction and speed the instrumentation was designed to allow the derivation of the fundamental atmospheric surface layer parameters, friction velocity u_* , sensible heat flux H , Manin-Obukhov length L , and standard deviation in wind direction σ_θ , which help define the turbulent diffusion of plume material (Haugen, 1973). These parameters are defined as follows.

Friction Velocity

This is defined by

$$u_*^2 = - \overline{u'w'}$$

where u' and w' are the fluctuating components of the horizontal wind velocity and the vertical wind velocity, respectively. These can be derived directly from uvw anemometer data.

TABLE I

METEOROLOGICAL INSTRUMENTATION

Instrument	Output	Derived Data
(i) Tower Gill uvw anemometers } 10 and 30 m levels Thermistor probes	u, v, w (fast response, 0.5 s sampling rate) T (0.1 s sampling rate)	u, θ , σ_u , σ_v , σ , σ_θ , σ_u^* T, L, stability class based on σ_θ or $\Delta T/\Delta z$
(ii) Radiometer	Net radiation	
(iii) Doppler Acoustic Sounder	u, v, w } (50 m and up, 10 min average) σ_θ , σ_ϕ thermal structure, stability class (based on σ_θ), Z_1	Z_1 , stability class
(iv) Monostatic Acoustic Sounder	thermal structure	Z_1 , stability
(v) PIBAL-minisonde	u, θ , T (vertical profiles, hourly)	
(vi) Ground based observations	u, θ , T, RH (hourly)	

where:

- u - horizontal wind - x component (standard deviation σ_u)
- v - horizontal wind - y component (standard deviation σ_v)
- w - vertical wind - z component (standard deviation σ_w)
- $\bar{u}$ - mean horizontal wind
- θ - horizontal wind direction (standard deviation σ_θ)
- ϕ - vertical wind direction (standard deviation σ_ϕ)
- u^* - friction velocity
- T - temperature
- L - Monin-Obukhov Length
- $\Delta T/\Delta z$ - vertical temperature gradient
- Z_1 - mixing layer height
- RI - relative humidity

Sensible Heat Flux

This is defined by

$$H = C_p \rho_0 \overline{T'w'}$$

where C_p is the specific heat of air at constant pressure and ρ_0 is the density of air. T' is the fluctuation in air temperature. H can therefore be derived directly from the fast response temperature measurements and the vertical wind velocity measured with the uvw anemometer.

Monin-Obukhov Length

This parameter may be thought of as describing the relative effects of mechanical and thermal turbulence and is defined as

$$L = \frac{u_*^3 T}{kg \overline{w'T'}}$$

where k is Von Karman's constant and g is the acceleration due to gravity.

All the parameters necessary to determine L directly are measured by tower instrumentation.

Standard Deviation of Horizontal Wind Direction

This is determined by

$$\sigma_\theta = \sqrt{\sum_{i=1}^N (\theta_i - \bar{\theta})^2 / N}$$

where θ can be calculated from the v and u components of the wind, measured by the uvw anemometer ($\theta = \tan^{-1}(v/u)$).

Unfortunately, due to mechanical problems experienced with the aging telescopic meteorological tower it was not possible to erect it to its full 30-m height. Instrumentation at only one level (15 m) was thus used. Data on temperature and wind gradients in the surface layer were therefore not available.

Data from the meteorological tower were logged and stored on tape. This was backed up by chart recorder traces. Data logger malfunction lead to the partial loss of tape information, which precluded ready analysis by computer. Data had to be extracted and analyzed manually from the charts and unfortunately were not as complete as planned. However, values of u , T and σ_3 were obtained from the tower measurements.

2.5 Data Analysis

2.5.1 Plume Dilution Factor.

The maximum concentration, $\chi_{\max}$, was estimated by interpolation between experimental points. The corresponding dilution factor was then obtained by dividing $\chi_{\max}$ by the measured SF_6 release rate, Q . The plume profile needs to be sufficiently well defined to enable the maximum concentration to be determined accurately.

2.5.2 Standard Deviation of the Lateral Plume Distribution

The lateral standard deviation of the plume is used in Gaussian models to describe the lateral distribution of the plume, perpendicular to the plume direction. Irrespective of the actual profile (Gaussian or non-Gaussian) the standard deviation² S_y , may be defined as the square root of the second moment of the crosswind distribution of tracer concentration

$$S_y^2(x) = \int_{-\infty}^{\infty} \chi(x,y)(y-\bar{y})^2 dy / \int_{-\infty}^{\infty} \chi(x,y) dy \quad (1)$$

where the position of the plume centerline is given by

$$\bar{y}(x) = \int_{-\infty}^{\infty} \chi(x,y)y dy / \int_{-\infty}^{\infty} \chi(x,y) dy \quad (2)$$

and where $\chi(x,y)$ is tracer concentration.

² For clarity we distinguish between the actual standard deviation of the plume, denoted S_y and defined by (1), and the standard deviation of a Gaussian profile fitted to the plume, denoted σ_y .

S_y may be estimated from measurements of tracer concentration made at a number of points across the plume using the methods described below. The case of sampler array perpendicular (or nearly perpendicular) to plume direction (ie, along y axis) is considered first in Section 2.5.2.1. In practice, depending on the wind direction and available sampler arrays, situations may occur where the plume does not intercept the array at a near perpendicular angle. The analysis of this situation is slightly more complex and is discussed in Section 2.5.2.2.

2.5.2.1 Plume Perpendicular to Array

(1) Direct Determination

If the density of sampling points is sufficient to clearly resolve the plume profile then the standard deviation may be directly determined by numerical integration over the profile using formulas (1) and (2) above. Even more simply, if N evenly spaced and symmetrically distributed measurements of plume crosswind concentrations x_i , are available, then the experimental standard deviation is given approximately by (Pasquill, 1974)

$$S_{y_{exp}}^2 = \frac{\sum_{i=1}^N x_i (y_i - \bar{y}_{exp})^2}{\sum_{i=1}^N x_i} \quad (3)$$

where $\bar{y}_{exp}$ is the experimental plume centerline given by

$$\bar{y}_{exp} = \frac{\sum_{i=1}^N x_i y_i}{\sum_{i=1}^N x_i} \quad (4)$$

The number of measurements N must be sufficient to accurately define the plume. A possible drawback to this method is that the points at the plume extremes are weighted most heavily, thereby tending to magnify the larger relative error in these points.

(2) Fit of Gaussian to Observed Profile

A Gaussian profile

$$x(y) = C_0 \exp[-(y-\mu)^2/2\sigma_y^2] \quad (5)$$

may be fitted to data by minimizing the variance

$$\sum_{i=1}^N (x_i - x(y_i))^2$$

where x_i are the measured concentrations and $x(y_i)$ are the concentrations predicted by (5).

Note that for a Gaussian profile the lateral standard deviation defined by (1) is $S_y \equiv \sigma_y$.

A measure of goodness of fit, ie, how well the observed profile approximates a Gaussian (Neuwstadt et al, 1979; Davis et al, 1981), is given by the normalized variance

$$r = \frac{\sum_{i=1}^N (x_i - x(y_i))^2}{\sum_{i=1}^N (x_i - \bar{x})^2}$$

$$\text{where } \bar{x} = \frac{\sum_{i=1}^N x_i}{N}.$$

The parameters C_0 (centerline concentration), μ (plume centerline location) as well as σ_y can be adjusted to optimize the fit. σ_y obtained in this way gives an estimate of the lateral standard deviation of the plume, S_y .

The disadvantage of this method of determining S_y is that it makes the sometimes unwarranted assumption that the plume profile is approximately Gaussian.

2.5.2.2 Plume Non-Perpendicular to Array

In certain cases the plume may intersect the array non-perpendicularly. Corrections must therefore be applied to extract S_y . Two methods were used:

(1) Plume Projection

The geometry of the situation is shown in Figure 2 where the plume intersects the sampler array at angle θ to the array normal. Array concentrations C_i and distances s_i along the array can be projected onto the crosswind, y , axis (Pasquill, 1974) by taking

$$y_i = s_i \cos \theta \quad (7)$$

This gives

$$S_y = S_{obs} \cos \theta \quad (7)$$

where S_{obs} is the standard deviation of the profile observed along the sampler array. S_{obs} can be calculated as in Section 2.5.2.1.

Obviously this method would be expected to work best when θ is small, as it takes no account of the dependence of concentration on downwind distance x .

(2) Method of Davis (1984)

For the case where the angle between the array and the crosswind axis is large, another method has been recently suggested. This explicitly takes the x (downwind) distance dependence into account and entails fitting the following expression to the profile measured along the array

$$x(x,y) = C_0(x_0) \exp [-y^2/2\eta^2] \quad (8)$$

where $\eta = px^q$ and $C_0(x_0)$ is the plume centerline concentration. In (8), the centerline lateral position is taken as $y = 0$. Figure 2 shows the geometry of the situation. A non-linear least squares fit of the data to (8) determines p and q . Davis (1984) suggests initial guesses of $p = 1$ and $q = 0.7$ to allow the fit to converge rapidly. Our experience confirmed this.

It can be shown that

$$\lim_{x \rightarrow x_0} \eta(x) = px_0^q = \sigma_y(x_0) \quad (9)$$

thereby giving σ_y at the distance x_0 , where the plume centerline intersects the array.

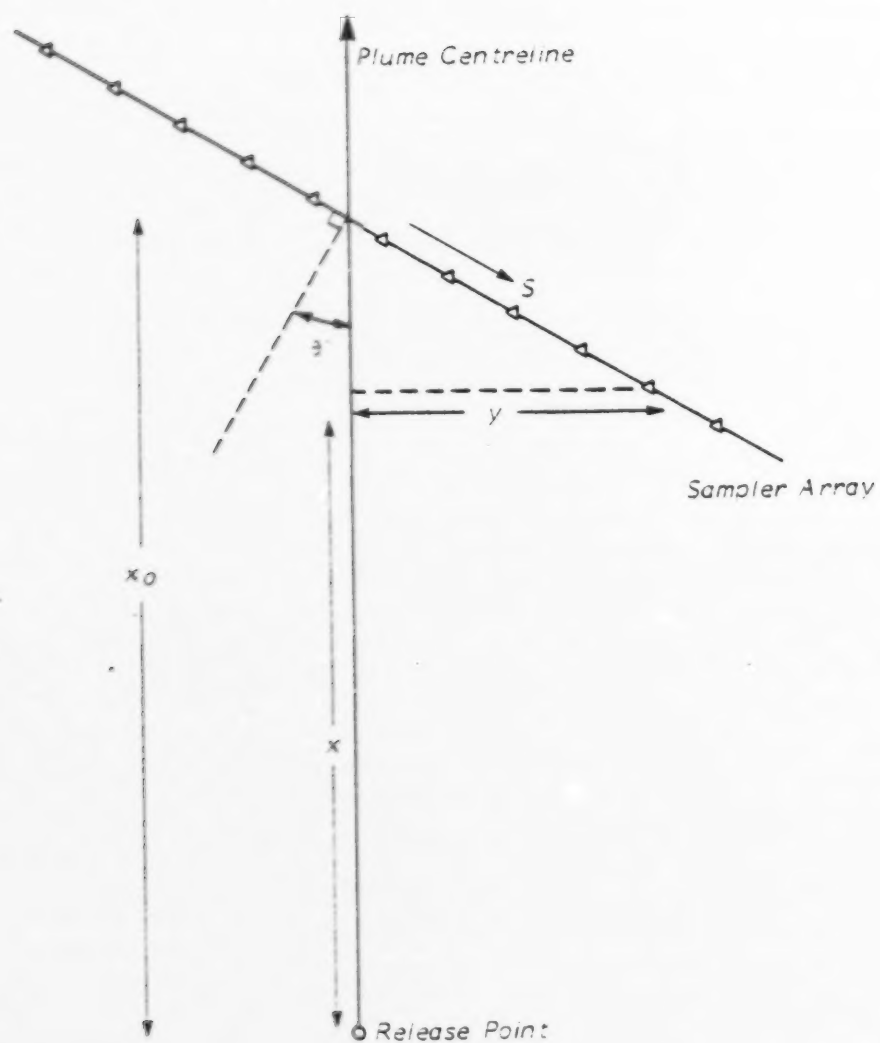


FIGURE 2
 PLUME CENTRELINE SAMPLER ARRAY GEOMETRY
 FOR A NON-PERPENDICULAR INTERSECTION ANGLE

Dabbert and Dietz (1983) suggest a method where "corrected" plume concentrations are projected onto the crosswind direction. Corrections to projected concentrations are made by assuming that concentration is inversely proportional to range (the distance between release and sampling point). The method of Davis (1984) has the advantage of treating the downwind dependence as a variable to be fitted to the data and hence appears to involve fewer empirical assumptions.

2.5.3 Standard Deviation of the Vertical Plume Distribution

For a ground level release this parameter can be defined at a particular downwind distance x as

$$S_z^2(x) = \int_0^\infty \chi(x,z) z^2 dz / \int_0^\infty \chi(x,z) dz \quad (10)$$

Again, for a Gaussian plume, $\sigma_z \equiv S_z$.

S_z may also be estimated in a number of ways.

(1) Experimental

If direct measurements of the plume profile are available at N heights then, for a ground-level release, the observed standard deviation S_z can be calculated in a similar way to S_y by carrying out a numerical integration over the vertical profile, or more simply by the approximate expression

$$S_{z_{\text{exp}}}^2 = \sum_{i=1}^N x_i z_i^2 / \sum_{i=1}^N x_i \quad (11)$$

In the latter case the N measurements should be evenly spaced and sufficiently close to each other to define the plume profile reasonably well, to ensure that $S_{z_{\text{exp}}}$ is a good approximation to the actual standard deviation.

If no direct measurements of the vertical profile are available then S_z may be estimated from ground level measurements as discussed in (2) and (3) below.

(2) From Plume Centerline Dilution
Factor and Lateral Standard Deviation

The vertical extent of a plume from a ground-level release may be estimated by assuming that the plume is bi-Gaussian in which case the plume centerline dilution factor at distance x is

$$\frac{x_{\max}}{Q} = (\pi \bar{u} \sigma_y \sigma_z)^{-1} \quad (12)$$

$x_{\max}/Q$ and σ_y are available from ground-based measurements and hence σ_z may be estimated as σ_z from (12).

(3) From Plume Crosswind Integrated
Concentration and Source Term

Again, for a Gaussian plume it can be shown that

$$\sigma_z = \sqrt{2/\pi} \quad Q(C_{CWI} \bar{u})^{-1} \quad (13)$$

where Q is the source term (release rate) and C_{CWI} is the crosswind integrated distribution

$$C_{CWI} = \int_{-\infty}^{\infty} x(x, y, 0) dy \quad (14)$$

Note that this method is only readily applied when the actual crosswind profile is directly measured, ie, when the sampler array is perpendicular (or at least nearly perpendicular to the plume). However, this method does provide a value of σ_z that preserves mass balance, and incorporates only direct measurements, so should be preferred over method (2).

3.0 RESULTS AND DISCUSSION

Because the sampler arrays only covered a limited range of wind directions, potential test days exhibiting suitable weather conditions were selected in advance using meteorological forecasts from Power System Operations Division, Ontario Hydro. A final decision on whether to proceed or not was made on the afternoon before, on the basis of the next day's forecast.

Upon arrival at the site a short term forecast was obtained and, based on this and the observed wind direction, the samplers were deployed, typically covering a single arc of about 40°. The sampler timers were set to take hourly samples beginning at a designated time. It usually took about two hours after arrival at the site to set up the equipment and begin the release. The tracer release was started before the samplers were switched on to allow sufficient time for the wind to carry the tracer to the sampling points.

Four tracer releases were carried out. On two out of four occasions the plume missed or only partially intercepted the sampler array as the winds did not move into the forecast direction in the time allocated for the experiment. This problem is particularly severe for light winds and it would have been desirable to have had more samplers available to cover a wider arc.

On October 24, 1984 two hours of tracer data were obtained during unstable conditions (Figure 3) and on November 16, 1984 four hours of data were obtained under largely neutral conditions (Figure 4). Table II summarizes the on-site meteorological data obtained during these days. One-hour average values are given to correspond to the tracer sampling times where appropriate. The meteorological picture is described in detail in Appendix A. In both cases, for the duration of the experiment, dispersion conditions were relatively uncomplicated over the transport distances investigated.

Figures 3 and 4 show the plume profiles measured on these days. Plume parameters estimated from these profiles included

- plume centerline dilution factor ($x_{\max}/Q$)
- plume lateral and vertical standard deviation.

The tracer data are summarized in Table III. The following observations may be made on the results.

3.1 Plume Direction

Comparison of Tables II and III shows that in all cases the direction of the plume centerline corresponded well with the wind direction measured by PIBAL at the beginning of each sampling hour. The centerline was taken as the first moment of the observed lateral profile.

3.2 Source Term and Dilution Factor

On November 16, the total amount of tracer released (as determined by the measured flow rate and the duration of the release) was compared to the total weight loss of the cylinder.

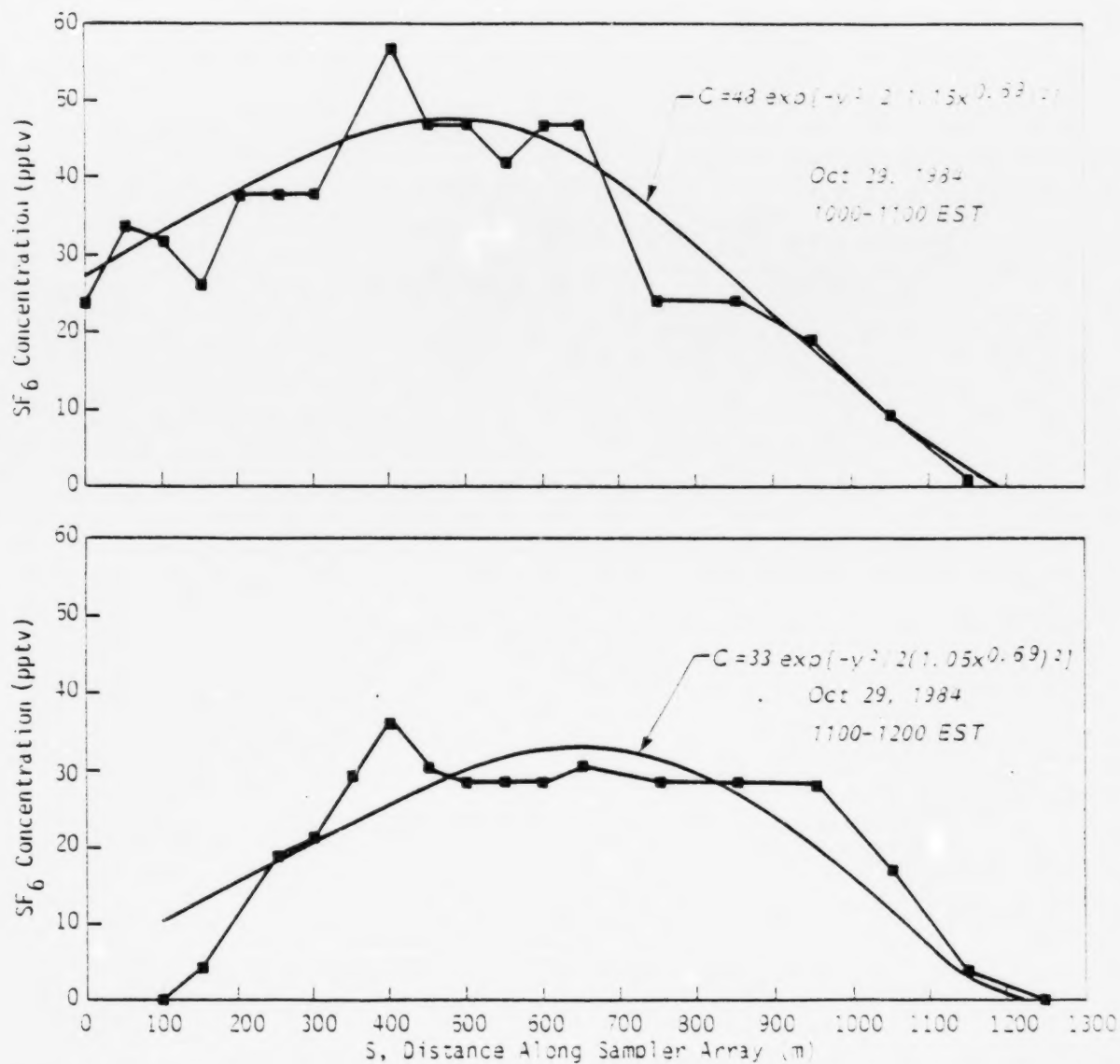


FIGURE 3

PLUME PROFILES OBSERVED ON OCTOBER 24, 1984, SHOWING TRACER CONCENTRATION VS SAMPLER POSITION ALONG THE SAMPLING ARRAY. THE SMOOTH LINES IN EACH CASE ARE OBTAINED BY FITTING THE DATA TO EQUATION (6) TO EXTRACT σ_y (SEE TEXT)

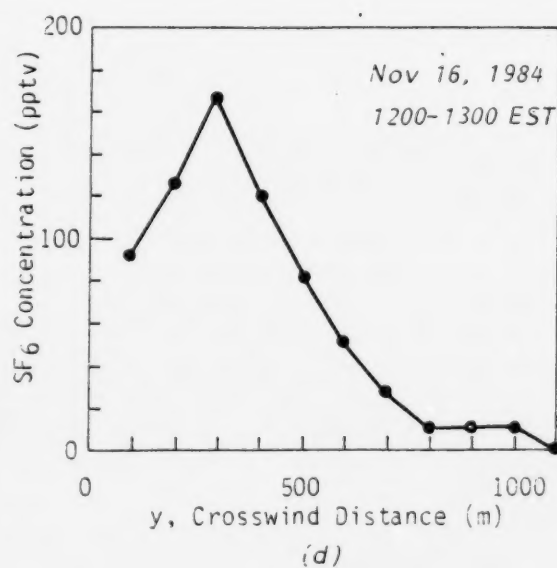
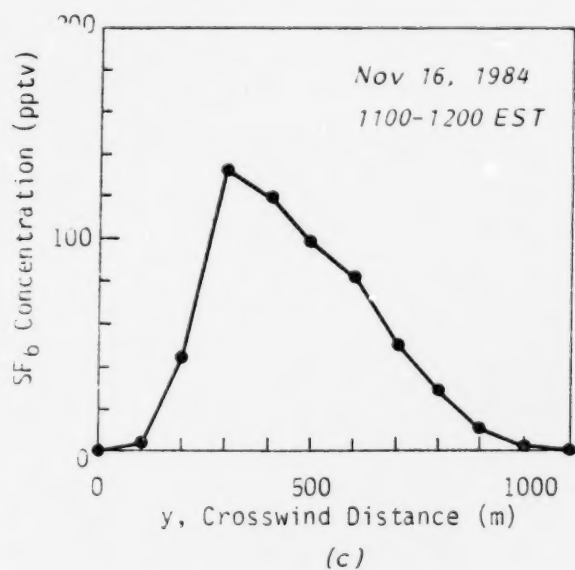
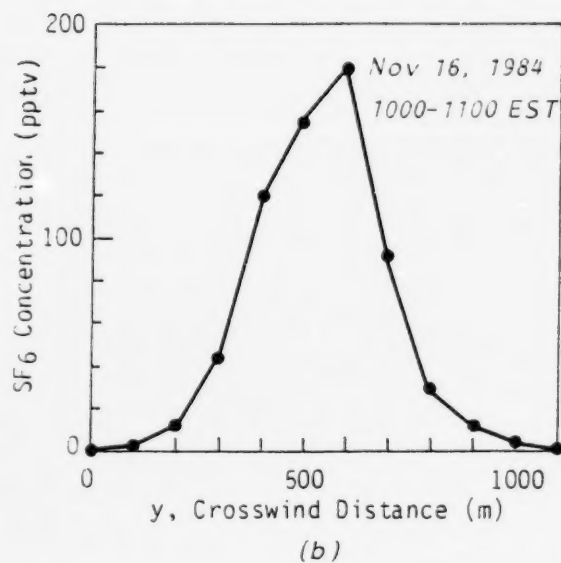
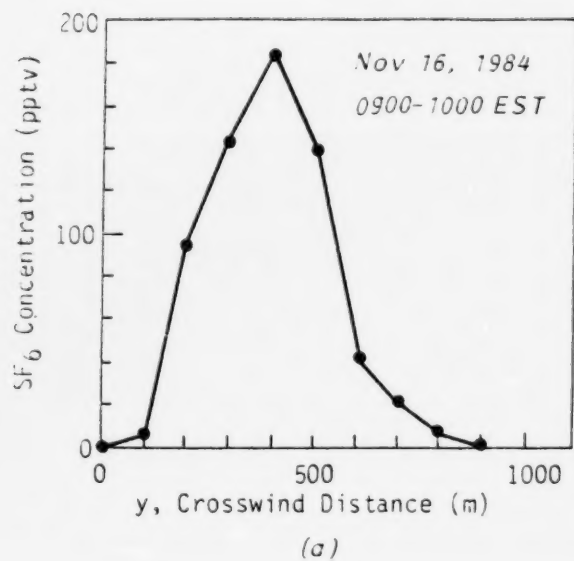


FIGURE 4
PLUME PROFILES OBSERVED ON NOVEMBER 16, 1984.
TRACER CONCENTRATION IS PLOTTED AGAINST
CROSSWIND DISTANCE y .

TABLE II
SUMMARY OF METEOROLOGICAL DATA

Meteorological Data													
Date/Time (EST)	PIBAL			Ground Level Observations				Doppler Acoustic Sounder			uvw Anemometer (15 m)		
	u_{50m} ($m\ s^{-1}$)	θ (° from)	Temperature Profile in Lower Atmosphere	u ($m\ s^{-1}$)	θ (° from)	T (°C)	RH (%)	Thermal Structure	σ_w value (50 m average) ($m\ s^{-1}$)	Stab (based on σ_w)	$\frac{u}{w}$ ($m\ s^{-1}$)	σ_u (degrees)	σ_u (radians)
Oct 24													
9000	1.6	74	Unstable	-	-	-	-		-	-	-	-	-
1000	1.2	144	"	-	-	10.6	75	Convective, no capping	0.6	C	1.2	42.4	0.73
1100	3.0	190	"	3.6	204	12.8	67	"	0.7	B-C	3.2	10.5	0.18
1200	2.4	210	"	3.1	213	13	54	"	0.6	C	3.4	12.0	0.21
Nov 16													
900	-	-		5.1	255	2.8	82	well mixed, no structure	- ^a	-	-	-	-
1000	-	256	neutral- slightly unstable	7.7	260	2.6	81	"	-	-	-	-	-
1100	-	264		6.7	265	3.2	78	"	-	-	8.2	11.6	0.20
1200	6.0	256		7.7	270	3.6	67	"	-	-	8.7	13.7	0.24
1300	5.8	252		6.2	250	2.8	70	"	-	-	12.5	11.8	0.20

^a data quality poor

^b one hour average for preceding hour

TABLE III

SUMMARY OF TRACER DATA

Date	Time (EST)	Q (sl. min ⁻¹)	χ_{max} (pptv)	C_o (pptv)	χ_{max}/Q (s m ⁻³)	x_o (km)	S_y (m)	y_{exp} (m)	σ_y (m)	σ_z (1) (m)	σ_z (2) (m)	C_{CWI} (pptv.m)	Plume Centerline Direction (° from)	θ_{int} (°)
Oct 24/84	1000-1100	3.77	57	48	8.7×10^{-7}	1.93	-	166	212	550	-	-	193	57
	1100-1200	3.77	36	32	5.5×10^{-7}	1.76	-	148	190	799	-	-	196	54
Nov 16/84	0900-1000	6.50	185	187	1.71×10^{-6}	2.31	141	133	138	206	195	6.38×10^{-4}	255	6
	1000-1100	6.50	180	180	1.67×10^{-6}	2.32	154	152	140	153	162	6.40×10^{-4}	258	9
	1100-1200	6.50	132	130	1.20×10^{-6}	2.32	194	173	180	176	171	5.86×10^{-4}	254	5
	1200-1300	6.50	165	155	1.53×10^{-6}	2.30	271	247	195	69	83	8.16×10^{-4}	252	3

Q is the source term (release rate of SF₆) χ_{max} is the maximum concentration observed along the sampler array C_o is the plume centerline concentration obtained by fitting the experimental data to a Gaussian distribution χ_{max}/Q is the maximum dilution factor x_o is the downwind distance at which χ_{max} occurs S_y is the lateral standard deviation determined by integration over the profile (Equation 1) $S_{y_{exp}}$ is the lateral standard deviation determined from measured concentrations alone (Equation 3) σ_y is the lateral standard deviation obtained (1) using the method of Davis (for Oct 24/84 data); $\sigma_z(1)$ is the vertical standard deviation obtained using centerline dilution factor and lateral standard deviation $\sigma_z(2)$ is the vertical standard deviation obtained using centerline dilution factor and crosswind integrated concentration C_{CWI} is the crosswind integrated concentration θ_{int} is the angle between the plume direction and the normal to the sampler array

These two values differed by about 2%, which is within the stated limits of accuracy of the flow-controller (4%). SF_0 concentration measurements (at plume centerline) were typically reproducible within 5% and the calibration was accurate to about 13% (Handy, 1985b) indicating that the values of observed plume dilution factors (x_{max}/Q) should be accurate to within about 20%. The plume dilution factor was taken to correspond to the highest concentration actually observed (x_{max}) and not to the centerline concentration (C_0) obtained by fitting data to a Gaussian. Because the sampler spacing was in all cases sufficiently dense to define the plume well, x_{max} and C_0 in practice usually differed by <10% on November 16 (see Table III). The larger deviations observed on October 24, 1984 were due to the greater departure of the observed profiles from a Gaussian shape (Figure 3).

3.3 Lateral Standard Deviation

For the data of November 16, the plume intersected the array nearly perpendicularly, so that the correction for the angle of interception was small (<1%). Accordingly, the data were analyzed assuming a perpendicular array.

The standard deviation was calculated firstly by numerical integration (using Simpson's rule) taking the integration step-size as the inter-sampler distance, and secondly by the simple formula of Equation 3. These are denoted by S_y and S_{yexp} , respectively, in Table III.

The lateral standard deviation was also calculated by fitting the experimental points to a Gaussian distribution (Equation 5) using C_0 , μ and σ_y as fitting parameters. Values obtained in this way are denoted by σ_y in Table III.

Values obtained using these three methods differed by less than 10%. Therefore, for practical purposes the use of Equation 3 is recommended as it is simple and does not involve the assumption that the plume is nearly Gaussian in shape.

As discussed in Section 3.2 the calculation of S_y and S_{yexp} requires an evenly spaced distribution of experimental points. When some points were not available (due, for example, to sampler failure) a value was interpolated using adjacent points. This is not expected to lead to significant error as sufficient points were always available to accurately define the plume profile. For the data of 1200-1300 EST, November 16 when only part of the plume was captured, the plume was assumed to be symmetrical about the point of maximum concentration and only the fully resolved half of the plume was used.

On October 24 the angle of intersection of the plume with the sampler array deviated greatly from the perpendicular. Accordingly, the two methods given in Section 2.5 were used to estimate the lateral standard deviation.

Table III shows firstly the values (denoted S_y) obtained using the projection method (Section 2.5.2.2). For the period 1000-1100 EST, October 24, the plume was only partially captured so S_y was estimated in two ways: (1) by assuming that the plume was symmetrical about the maximum observed concentration and (2) by linearly extrapolating the line joining the last two points, on the end of the measured profile, to zero concentration. These two methods gave values of S_y which agreed well, 166 and 161 m, respectively.

For comparison, the method suggested by Davis (1984) was also used. The accuracy of this method depends on being able to define the plume centerline concentration well. The centerline position may be estimated either by assuming (1) that it corresponds to the position of the maximum concentration; or (2) that it corresponds to the first moment of the measured profile (as is the case for a perpendicular array). For the data of 1100-1200 EST (where the plume was fully resolved), assumption (1) resulted in a poor fit to the data because of the asymmetrical position of the point of maximum concentration. Assumption (2) allowed a much better fit to the data (see the fitted profile shown in Figure 3). C_0 (the centerline concentration), p and q in Equation (8) were treated as fitting parameters. The best fit parameters were $C_0 = 33$ pptv, $p = 1.05$ and $q = 0.69$. This gave σ_y ($x_0 = 1760$ m) = 182 m compared to $\sigma_y = 148$ m obtained by projection.

Because of the uncertainty in the best choice of centerline the sensitivity of the derived value of σ_y was investigated by assuming a number of different centerline positions and then fitting expression (8) in each case to the data of 1100-1200 EST. (Note that each centerline position corresponds to a slightly different downwind distance.) As a measure of goodness of fit the normalized variance was also calculated. Figure 5 shows the results. Over a range of reasonable choices of centerline position (compare with Figure 3) the inferred value of σ_y changes little. The variance is also minimized in this range, as would be expected. The choice of the first moment (center of gravity) of the observed profile as centerline would therefore appear to generate little error even if the array is significantly skewed with respect to the plume.

For the data of 1000 to 1100 EST, where the plume was not fully resolved, the centerline was estimated by extrapolating the missing part of the profile (as done for the projection method

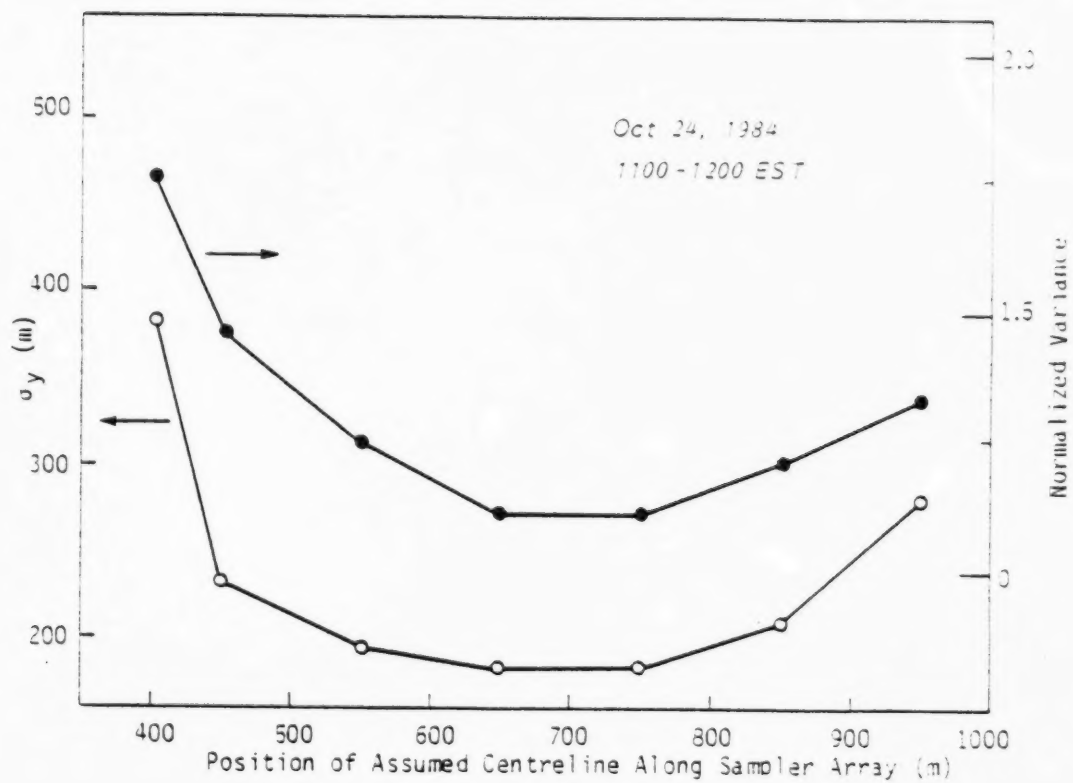


FIGURE 5
PLOT OF PLUME LATERAL STANDARD DEVIATION AND
VARIANCE OF FIT AGAINST ASSUMED CENTRELINE POSITION.
(COMPARE WITH PROFILE SHOWN IN FIGURE 3b)

above) and taking the first moment of the resulting profile. A fit to Equation 6 gave $C_0 = 48$ pptv, $p = 1.15$ and $q = 0.69$ giving $\sigma_y = 212$ m (compared to 161 m obtained by projection).

For comparison, values of σ_y were also estimated by fitting Equation 8 to the half-profile fully resolved (for 1000-1100 EST). Again there was a problem in deciding the position of the plume centerline. Assuming that it corresponded to the point of maximum observed concentration ($S = 400$ m in Figure 3) gave $\sigma_y = 231$ m. Taking it as the estimated first moment of the extrapolated profile as above ($S = 475$ m in Figure 3) gave $\sigma_y = 226$ m. Both values are within 10% of the value of 212 m obtained by fitting to the entire extrapolated profile. This again indicates that derived σ_y 's are not very sensitive to the accuracy with which the plume centerline position is estimated.

In both cases the standard deviations derived by the method of Davis (1984) are approximately 20% greater than the value derived by the projection method. The projection method is less likely to be reliable as the dependence of concentration on downwind distance is ignored. In these examples, the downwind distances of the two edges of the profile are very different (for 1100-1200 EST the extremes of the plume are at $x \sim 1300$ m and $x \sim 2200$ m, respectively), thereby potentially giving rise to significant error.

3.4 Vertical Standard Deviation

No direct measurements of vertical plume profiles were obtained on October 24 or November 16. (The balloon sampling system was used to fly a single sampler to a height of 50 m on October 24 at 1100 EST and a half-hour sample indicated a tracer concentration of 32 pptv, not significantly different from the concentration of 30 pptv measured at ground level near the balloon location.) Values of σ_z were therefore inferred by the two methods described in Section 2.5.3, both of which make the implicit assumption that the vertical distribution is Gaussian. For November 16, the two methods gave values of σ_z which agree well. For the data of October 24 the method based on crosswind integrated concentration, C_{CWI} , was not used as C_{CWI} was not directly available due to the non-perpendicular plume intersection angle.

3.5 Comparison with Model Predictions

As discussed earlier, the results of experimental tracer studies can be used for two purposes: (1) providing site specific data on actual concentration patterns under various meteorological

conditions, and (2) validating and testing the performance of dispersion models.

To illustrate the latter, the predictions of the following models are compared to maximum observed dilution factors in Table IV. The models compared consist of two standard Gaussian models and CRDM, a model implemented by Ontario Hydro Research Division which describes the dispersion of material released in the surface layer. Model input was taken from Table III. Hourly average wind speeds as measured by the 15 m tower were used. The models are briefly described below:

- (i) The first model was a Gaussian plume model with dilution factors according to Turner (1969).

This is a commonly used Gaussian model. Dilution factors graphed by Turner are based on σ_y and σ_z curves generated for each Pasquill-Gifford stability class (Pasquill, 1961; Gifford, 1961). The experiments on which these curves are based are short-range diffusion tests carried out for surface-based releases at distances less than 1 km for 10-minute averaging times.

Dilution factors given in Table IV are corrected to correspond to 1-hour averaging time by assuming that the dilution factor is inversely proportional to the averaging time to the power 0.2 (Turner, 1969).

- (ii) The second model was also a Gaussian plume model, using σ_y and σ_z based on the formulas of Briggs (1973) and Smith (1972) and Hosker (1974), respectively.

This model was recommended in the draft report of the National Working Group on Atmospheric Releases of Radio-isotopes (unpublished) and by the draft Canadian Standards Association, Standard 288.2 (unpublished).

- (iii) CRDM (Wright, 1983) is a model where the vertical diffusion of the plume is treated by similarity theory (based on expressions given by Van Ulden, 1978). Horizontal diffusion is treated in a Gaussian manner with σ_y given either by the expressions of Briggs (1973) for each Pasquill-Gifford stability class, or by the formula of Pasquill (Pasquill 1976, Irwin 1983) which gives σ_y in terms of downwind distance and σ_θ .

The data set is too small to draw conclusions of great significance, but it may be noted that CRDM appears to perform considerably better than the other models.

TABLE IV
COMPARISON OF MEASURED PLUME
DILUTION FACTORS, χ/Q , WITH MODEL PREDICTIONS

Date/Time	χ/Q ($s\ m^{-3}$)	Model Predictions			
	Measured	Gaussian (1) ^a	Gaussian (2) ^{a,b}	CRDM ^{b,c}	
				(1)	(2)
Oct 14/84					
1000-1100	8.7×10^{-7}	3.5×10^{-6}	4.4×10^{-6}	7.3×10^{-7}	7.7×10^{-7}
1100-1200	5.5×10^{-7}	3.7×10^{-6}	4.9×10^{-6}	9.3×10^{-7}	8.1×10^{-7}
Nov 16/84					
900-1000	1.7×10^{-6}	4.4×10^{-6}	3.2×10^{-6}	2.2×10^{-6}	1.7×10^{-6}
1000-1100	1.7×10^{-6}	3.7×10^{-6}	2.7×10^{-6}	1.9×10^{-6}	1.3×10^{-6}
1100-1200	1.2×10^{-6}	3.5×10^{-6}	2.5×10^{-6}	1.8×10^{-6}	1.0×10^{-6}
1200-1300	1.5×10^{-6}	2.4×10^{-6}	1.8×10^{-6}	1.3×10^{-6}	9.1×10^{-7}

a Gaussian (1) is based on Turner (1969), Gaussian (2) is based on Briggs (1973) and Hosker (1974). For Oct 24, 84 the stability class was obtained from the Doppler acoustic sounder. For Nov 16, 84 it was inferred to be D, neutral (Turner 1969), based on insolation and wind speed.

b Roughness length assumed to be -40 cm

c (1) uses Briggs (1973) expression for σ_y based on stability class, (2) uses the expression of Pasquill (1976) which is based on σ_g .

Similar comparisons may be made between plume dimensions and model predictions, this is done for lateral plume dimensions below. No comparisons with parameters indicating vertical extent were made because of the lack of direct measurements.

Table V shows a comparison between measured lateral standard deviations and predictions using various methods. The schemes chosen for comparison are (1) the values graphed by Turner (1969) as a function of (Pasquill-Gifford) stability class and downwind distance; (2) the formulas given by Briggs (1973), again as functions of downwind distance and stability class; (3) the formula given by Pasquill (1976) expressing σ_y in terms of standard deviation in horizontal wind direction, σ_θ , and downwind distance (Irwin, 1983)). The agreement between predicted and experimental values can be seen to be reasonably good.

3.6 Designing Future Studies

As stated in the introduction a primary purpose of the present study was to gain experience in the operation of tracer systems. Based on the experience of this pilot study some suggestions are made below regarding the design of possible future studies.

- Because tracer studies are highly labour intensive (due to the personnel necessary to carry out meteorological measurements, tracer release, and sampler preparation, deployment and retrieval) it would be highly desirable to maximize the information retrieved from each experiment. A cost effective way of doing this is to increase the number of samplers, thereby enabling, for example, the use of multiple arrays at different downwind distances. Additional sequential samplers can be constructed based on the inexpensive design of Sawford and Manins (1979).
- Traditionally, one or more sampler arcs, arrayed perpendicular to the plume, have been used to define maximum plume concentrations and lateral plume dimensions at various downwind distances. However, more recently the advantages of using a sampling grid have been exploited in order to determine plume concentration patterns more fully (eg, Start et al 1983). This approach is particularly useful when dealing with complex terrain where complicated concentration patterns may arise, or in the case of elevated releases where it is often important to determine the downwind distances at which plume impingement and maximum ground level concentration occur. Obviously, the grid approach usually requires a greater number of samplers than that of using arcs, hence the use of the latter in this preliminary study.

TABLE V
COMPARISON OF PREDICTED AND
MEASURED LATERAL STANDARD DEVIATIONS

Date/Time (EST)	x_o (km)	Stab	σ_θ (degrees)	Turner (m)	Briggs (m)	Pasquill (m)	$S_{y_{exp}}$ (m)
<u>Oct 24/84</u>							
1000-1100	1.93	C(B)	10.5 ^a	208 (290)	194 (282)	186	226
1100-1200	1.76	C	12.0	180	178	198	182
<u>Nov 16/84</u>							
900-1000	2.31	D ^b	-	150	167	-	133
1000-1100	2.31	D	11.5	150	167	234	153
1100-1200	2.31	D	13.7	150	167	280	173
1200-1300	2.31	D	11.8	150	167	140	247

a 1/2 h average only

b stability class inferred from insolation and wind speed (Turner 1969)

- In certain cases routine emissions (tracers of opportunity) may be used to study dispersion. However, this may suffer from the following drawbacks: emission rates may be variable or difficult to accurately quantify; ambient concentrations may be too low to detect with sufficient time resolution; and there may be other sources in the vicinity. Visible tracers, such as oil fog, have often been used with striking success to obtain a comprehensive picture, of plume shape and motion with high time resolution, particularly in the short range (eg, Start et al, 1980, EPRI 1980).
- Under light wind conditions, it was found to be very difficult to anticipate the plume direction and place the samplers accordingly as actual winds are often not exactly as predicted. This problem was compounded in the present study by the fact that the premarked sampler arrays only intersected a limited angular sector of plume directions (for reasons of convenience). In future studies, potential sampler positions should cover as great an arc around the release point as possible to enhance the probability of being able to intersect the plume and obtain data, even under conditions where the actual wind direction differs significantly from that forecast.
- It is important to have reliable data logging systems given the expense of losing information. The Atmospheric Research Section is acquiring a new data logging facility which should meet this requirement.
- Certain modifications to the samplers may be necessary to carry out winter studies.

4.0 CONCLUSIONS

Sulfur hexafluoride tracer release and sampling systems for carrying out site specific atmospheric dispersion studies have been developed and tested. These were used in conjunction with a comprehensive array of meteorological instrumentation to relate the observed tracer concentration patterns to atmospheric conditions.

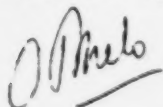
A particularly interesting application of this technique may be the investigation of the short-range dispersion conditions existing at Ontario Hydro's nuclear generating sites with emphasis being placed upon the effect of the building wake, local terrain and lakeshore siting. The tracer systems developed here are particularly suited for such studies of short-range dispersion from near-ground level releases.

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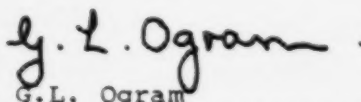
A tracer study involves a great deal of work by a number of people. C. Donovan, B. Handy, A. Lemyk, D. Wenglewick, T. Jarv and Y. Tam carried out much of the work. O. Melo, A. Kalvins and S. Wright provided useful advice.

Reviewed by:



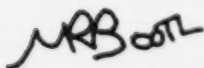
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APPENDIX A

DETAILED METEOROLOGICAL INFORMATION

(A) METEOROLOGY FOR OCTOBER 24, 1984

(1) Synoptic Analysis (Prepared by Y. Tam)

The surface synoptic weather maps of October 24, 1984 showed that, on this day, eastern North America was under the influence of a high pressure system.

This high pressure system was located over South Dakota and Nebraska on October 23 and moving eastward. It was so strong that it nearly dominated the weather over the entire US on October 24, except for the southeastern region, where a subtropical cyclone system was observed. There was an arctic cyclone system located over the central Quebec and northern Ontario areas. Associated fronts extended from Labrador through the Canadian prairies to the Pacific coast. Snow was observed in areas along these fronts.

However, none of these two cyclone systems had adverse effects on the weather conditions over the Great Lakes area. Typical high pressure weather was observed in the Lake Ontario area. For example, Trenton reported calm winds under sunny skies with a temperature of 3°C and a pressure of 1027 mb at 0100 EST, October 24. This condition persisted to 1300 EST; thereafter, cloudy skies were observed. At 1300 EST Trenton reported winds from the south at 18 km h⁻¹ (5 ms⁻¹), temperature 12°C and a pressure of 1026 mb. A streamline analysis of the surface flow on this day at 1100 Z showed a clockwise circulation over the Lake Ontario area. This confirmed the high pressure system weather pattern.

(2) On-Site Meteorological Data

(i) 15-m Tower

Due to malfunction of the data logger, only chart records of horizontal winds, u and v, were available for the period 0900 to 1200 EST. From these, half-hourly averages of mean wind speed and standard deviation in wind direction, σ_θ , were extracted by hand using values of u and v at one minute intervals. The data in Table A-I show that u increased over the time period, whereas σ_θ decreased as the winds picked up.

TABLE A-I

DATA ABSTRACTED FROM uvw ANEMOMETER (15 m)
OCTOBER 24, 1984

Time (EST)	$\bar{u}$ (ms^{-1})	σ_{θ} (degrees)
0900-0929	1.31	25.7
0930-0959	1.01	59.1
1000-1029	3.09	10.5
1030-1059	3.23	-
1100-1129	3.26	12.6
1130-1159	3.48	11.4

(ii) Pilot Balloon Soundings

PIBAL-minisonde soundings were made at 0845 EST (PIBAL only) and then hourly at 1000, 1100 and 1200. Single theodolite tracking was used. Results are plotted in Figures A1 (profiles of wind speed and direction) and A2 (temperature profiles). Figure A2 shows the dry adiabatic lapse rate for comparison. It can be seen that the measured temperature gradient was greater than the dry adiabatic lapse rate in the surface layer, implying an unstable atmosphere close to the ground.

(iii) Ground-Based Observations

Observations of wind speed and direction, pressure, RH and cloud were taken at the PIBAL release site at 0945, 1045 and 1145 EST. The data are summarized in Table A-II.

The net radiometer trace is shown in Figure A3 and the hourly averaged net radiation derived from this chart shown in Table A-III. As can be seen the net radiation increased sharply between 0800 and 0900 EST leading to the onset of unstable conditions.

(iv) Acoustic Sounders

Only vertical wind speed and standard deviation were available from the Doppler acoustic sounder (Radian) on this day. Horizontal wind data were not available due to instrument malfunction. Output data are given in Table A-IV. The vertical wind data appear to be of good quality. The stability class estimated from the Doppler data was primarily C for the time period of interest. This seems reasonable in comparison with the temperature profile data.

The Doppler structure displayed characteristics typical of convective atmospheric conditions with no temperature inversion (within 1000 m) capping the convective boundary layer. The inland sounder displayed similar structure.

(B) METEOROLOGY FOR NOVEMBER 16, 1984

(1) Synoptic Analysis (Prepared by Y. Tam)

The weather over Ontario on November 16, 1984 was dominated by a low pressure system. This low pressure system developed in Montana on November 14 and intensified rapidly as it moved eastward toward the Great Lakes area.

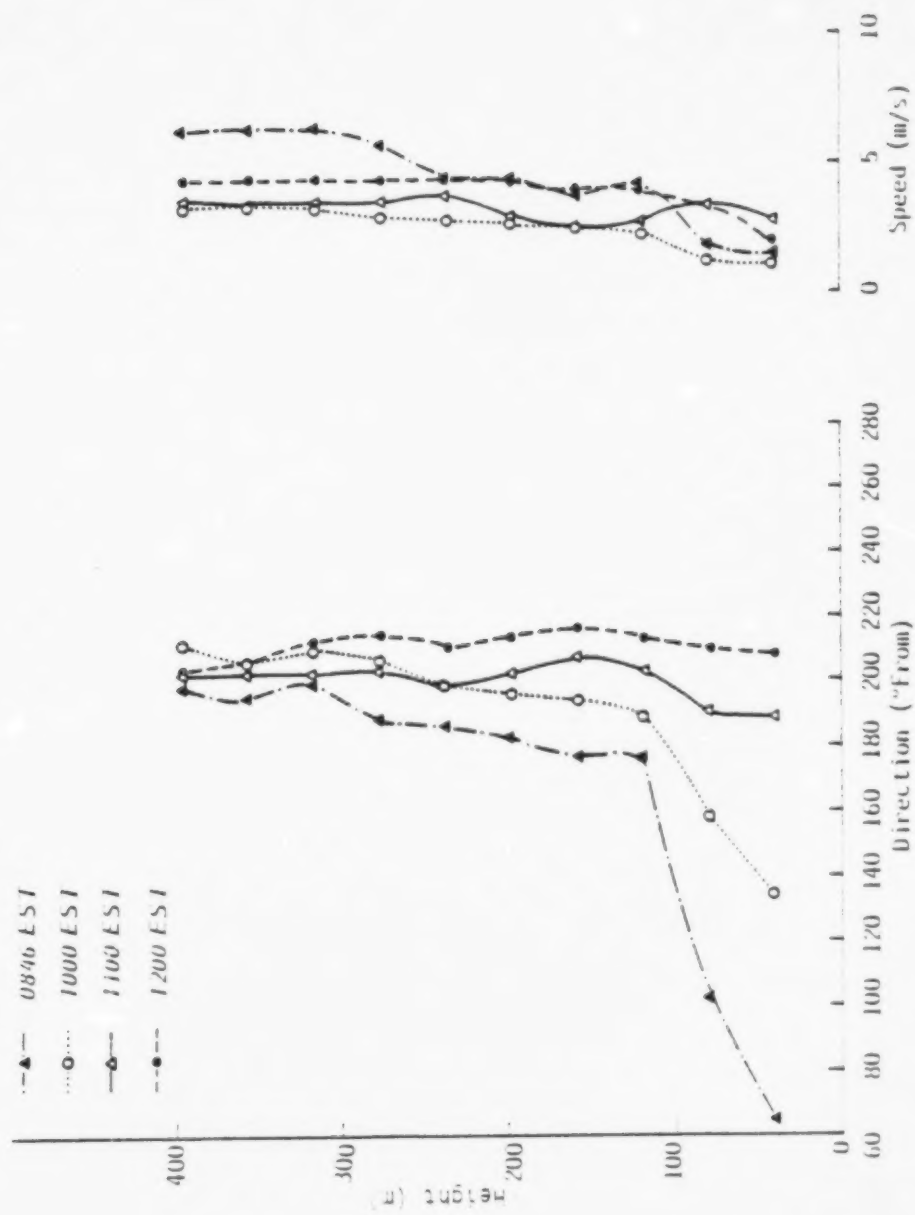


FIGURE A1
PROFILES OF WINDSPEED AND DIRECTION, OCTOBER 24, 1984

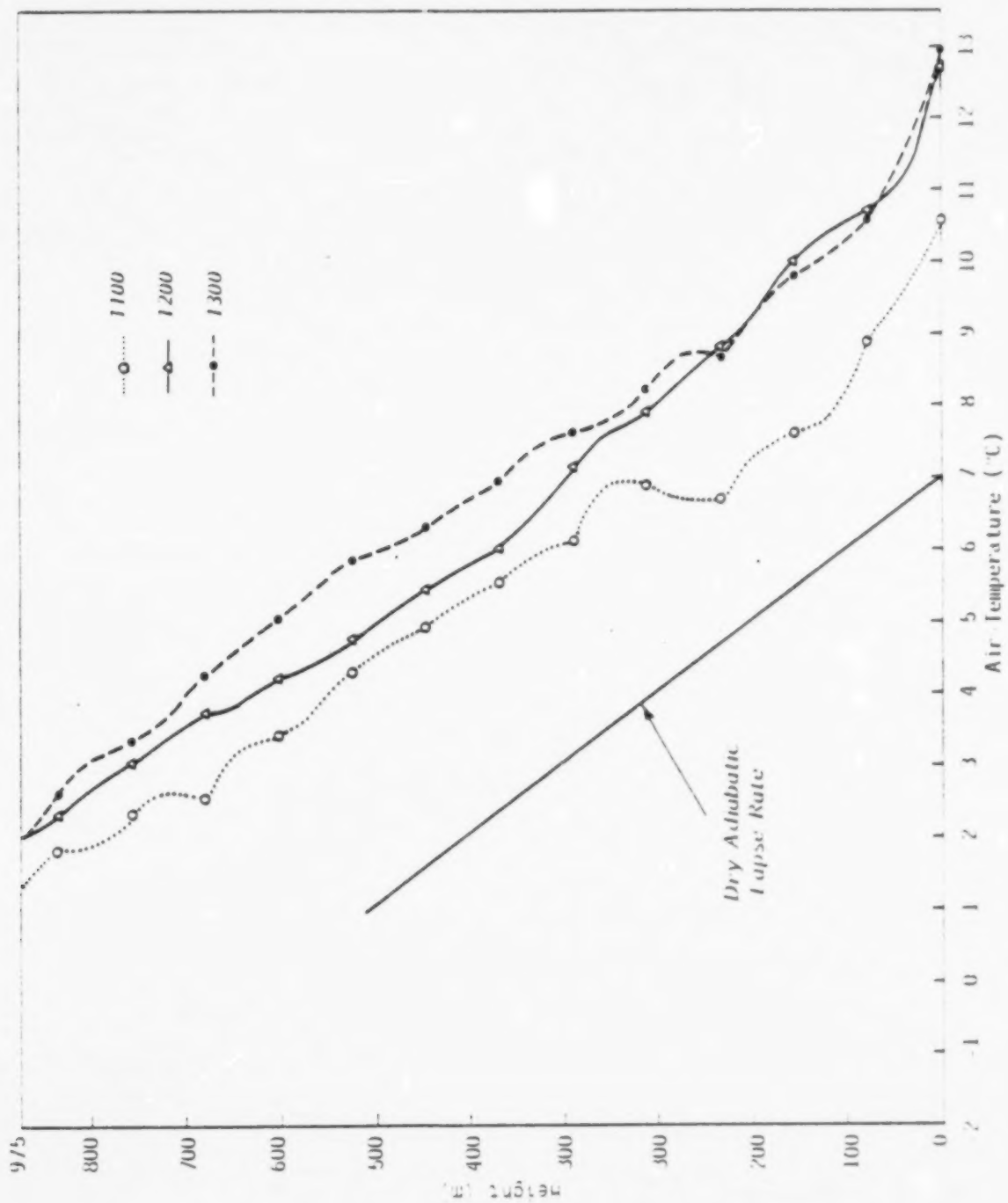


FIGURE A2

TEMPERATURE PROFILES, OCTOBER 24, 1984

TABLE A-II

GROUND BASED OBSERVATIONS (OCT 24, 84)

Time (EST)	Wind Speed (m s ⁻¹)	Direction (° from)	Temp °C	Pressure (mb)	RH (%)	Cloud	
						Type	Amt
0945	calm	calm	10.6	1026.6	75	Cu	1/10
						Ac	1/10
1045	3.6	204	12.8	1031.7	67	Cu	2/10
						Ac	1/10
1145	3.1	213	13.0	1031.5	54	Cu	1/10
						Ac	1/10

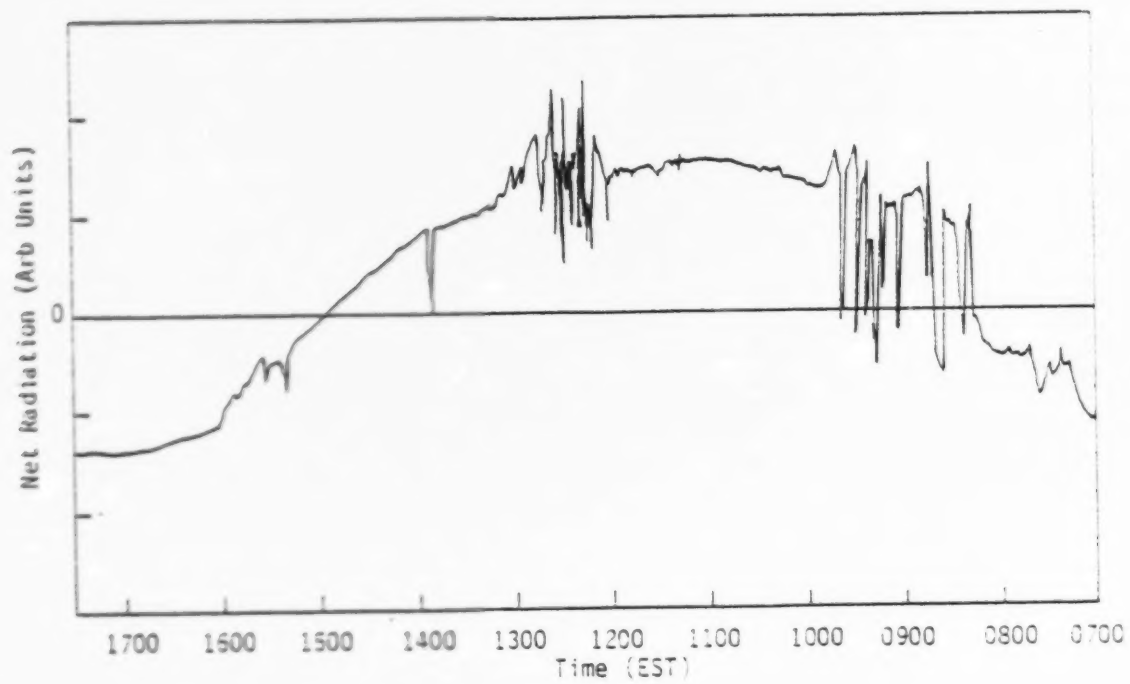


FIGURE A3
RECORD OF NET RADIOMETER OUTPUT, OCTOBER 24, 1984

TABLE A-III

NET RADIATION (OCTOBER 24, 84)

Time (EST)	Net Radiation (mJ m ⁻² h ⁻¹)
0800	0.026
0900	0.543
1000	0.758
1100	0.773
1200	0.788
1300	0.517
1400	0.205
1500	-0.251
1600	-0.640
1700	-0.711

TABLE A-IV
DOPPLER ACOUSTIC SOUNDER OUTPUT (OCT 24/84)

Time (EST)	Stability ^a (Class)	Vertical Wind Standard Deviation ^{a,c} (m s^{-1})	Vertical Wind w (m s^{-1}) + Standard Deviation σ_w (m s^{-1}) ^b						Height of Convective Layer ^d (m)
			50 m		75 m		100 m		
			w	σ_w	w	σ_w	w	σ_w	
1019	Unstable (C)	0.60	-0.3	0.5	-0.1	0.6	0.0	0.7	140
1029			-0.5	0.5	-0.8	0.5	-0.9	0.6	264
1038	Unstable (C)	0.57	-0.3	0.6	-0.3	0.6	-0.2	0.6	290
1056	Unstable (B)	0.75	-0.3	0.7	-0.6	0.9	-0.6	1.1	330
1101			0.2	0.8	0.2	0.9	0.2	1.1	360
1119	Unstable (B)	0.75	0.1	0.7	0.1	0.8	0.2	1.0	380
1128			-0.3	0.7	-0.3	0.6	-0.3	0.7	330
1137	Unstable (C)	0.64	-0.2	0.6	-0.2	0.7	-0.2	0.7	340
1155	Unstable (C)	0.59	-0.5	0.5	-0.5	0.5	-0.6	0.6	340
1201			-0.2	0.7	-0.3	0.9	-0.4	0.8	360

a 20 min average

b 10 min average

c The Doppler sounder automatically outputs an estimate of stability based on the standard deviation of vertical wind σ_w .

By 0100 EST, November 15, the center of this low was located over the border of Manitoba and Ontario with a warm front extending eastward to Quebec and Maritimes and a cold front southward to the US. Also, a pre-cold front trough was observed from Lake Superior through the east shore of Lake Michigan to the southern portion of the US. The general flow in the southern Ontario area was southerly according to this system. Precipitation in the form of snow and rain was observed throughout the province with showers in the southern part.

This system continued to move eastward. At 0700 EST, November 16, the low center was located in Quebec while the cold front had moved to the east of the Great Lakes. Strong westerly to southwesterly wind became predominant. Overcast skies and light snow showers were observed generally in southern Ontario as well as at the Wesleyville site.

(2) On-Site Meteorological Data

(i) 15-m Tower

Again, due to data logger malfunction, only chart records of horizontal winds, u and v , were available. Half-hourly averages of u and σ_θ were abstracted from u and v values, obtained at one minute intervals from the chart and are shown in Table A-V. The values were fairly constant throughout the duration of the experiment.

(ii) Pilot Balloon Soundings

PIBAL-minisonde soundings were made at 1000, 1100, 1200 and 1300 EST. Dual theodolite tracking was used. The data are shown in Figures A4 and A5. The data at 1000 EST and low-level data at 1100 EST were of poor quality because the primary theodolite lost sight of the balloon behind an obstacle. Comparison of the temperature gradient with the adiabatic lapse rate indicates a neutral to slightly unstable atmosphere.

(iii) Ground-Based Observations

Observations were made 10 minutes before each PIBAL release and are summarized in Table A-VI.

The net radiometer trace is shown in Figure A6 and the derived hourly averaged net radiation in Table A-VII. It can be seen that the insolation was weak leading to near neutral conditions.

TABLE A-V

DATA ABSTRACTED FROM uvw ANEMOMETER (15 m)
 NOVEMBER 16 1984

Time (EST)	$\bar{u}$ (m s ⁻¹)	σ_{θ} (degrees)
1000-1029	6.8	11.0
1030-1059	9.5	12.1
1100-1129	8.5	14.0
1130-1159	8.9	13.4
1200-1229	11.9	17.4
1230-1259	13.1	6.2

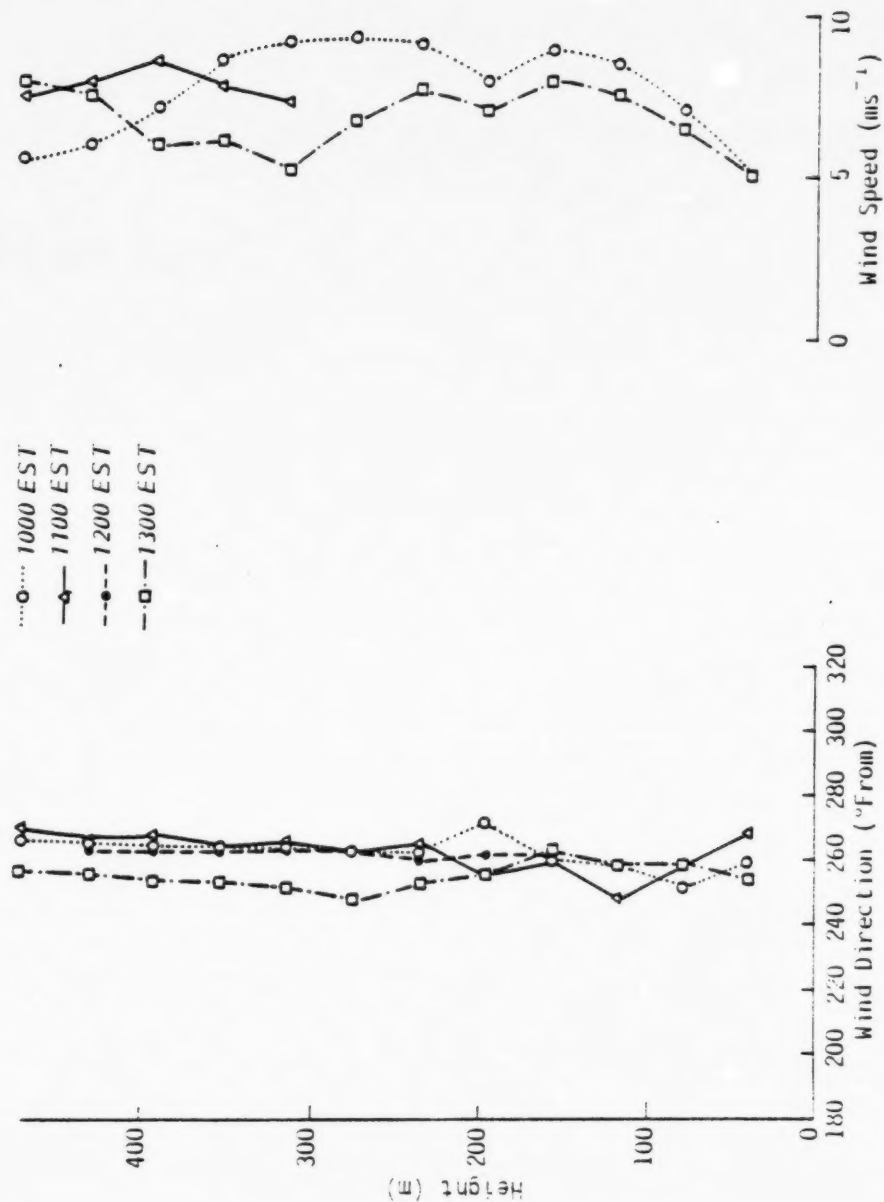


FIGURE A4
PROFILES OF WIND SPEED AND DIRECTION, NOVEMBER 16, 1984

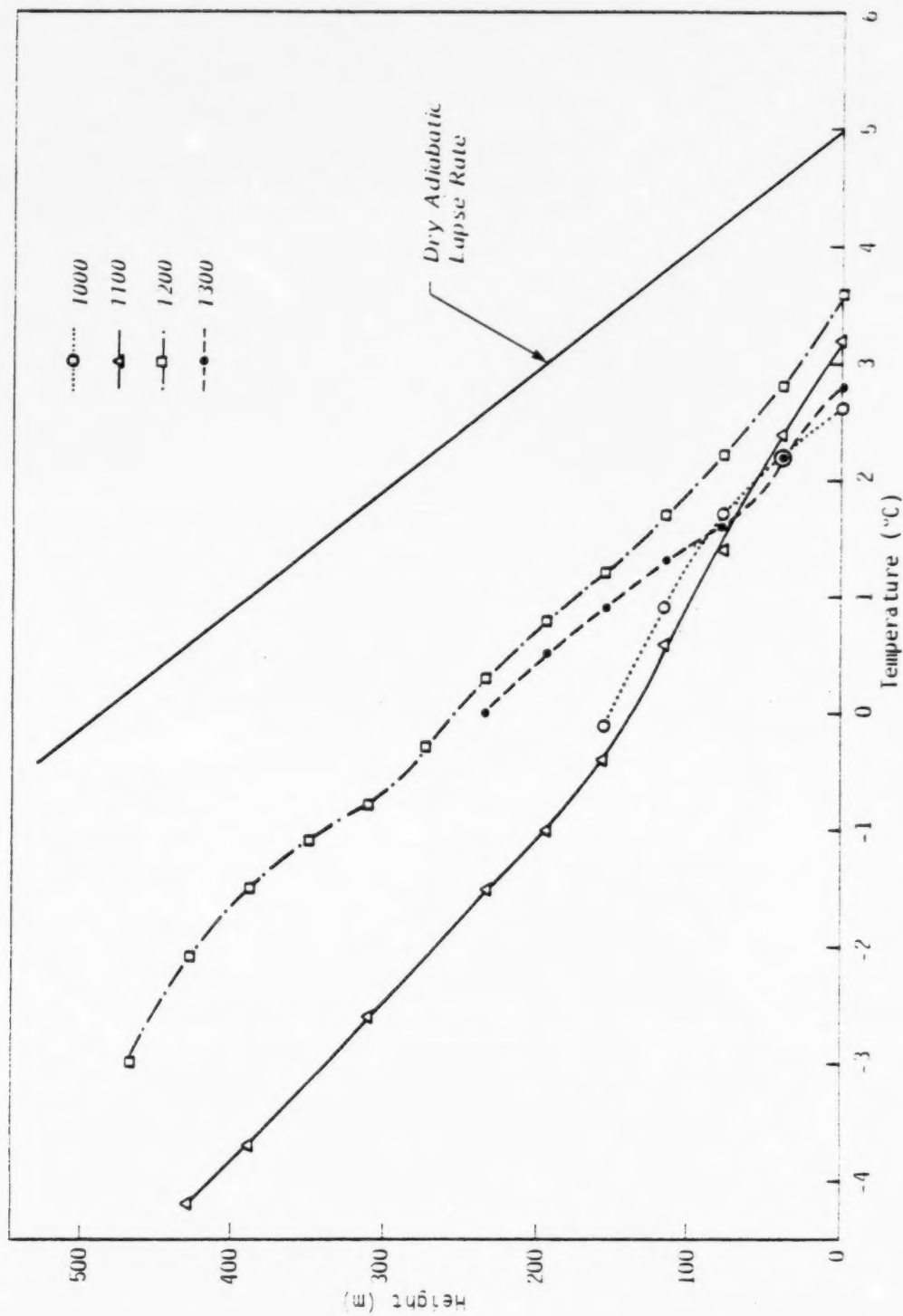


FIGURE A5
TEMPERATURE PROFILES, NOVEMBER 16, 1984

TABLE A-VI

GROUND BASED OBSERVATIONS (NOV 16, 84)

Time (EST)	Wind Speed ms ⁻¹	Direction (° from)	Temp (°C)	Pressure (mb)	RH (%)	Cloud	
						Type	Amt
0850	5.1	255	2.8	1013.0	82	SF	10/10
0950	7.7	260	2.6	1013.9	81	SF	6/10
						As	4/10
1050	6.7	265	3.2	1013.9	78	CF	3/10
						As	7/10
1150	7.7	270	3.6	1013.9	67	Cu	9/10

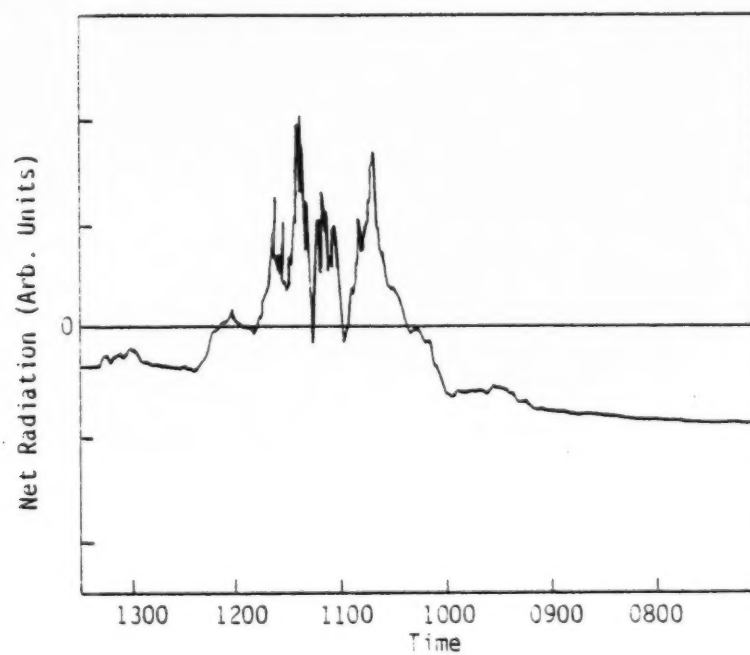


FIGURE A6
RECORD OF NET RADIOMETER OUTPUT, NOVEMBER 16, 1984

TABLE A-VII

NET RADIATION (NOVEMBER 16, 84)

Time (EST)	Net Radiation (mJ m ⁻² h ⁻¹)
0000	-0.461
0100	-0.461
0200	-0.466
0300	-0.471
0400	-0.461
0500	-0.461
0600	0.461
0700	-0.450
0800	-0.415
0900	-0.328
1000	0.138
1100	0.281
1200	-0.108

(iv) Acoustic Sounder

No wind data were available on this day due to low signal-to-noise ratios. These were possibly due to high winds, blowing over nearby trees, leading to higher noise levels. More care in Doppler siting will be necessary in future studies to ensure data recovery under high wind conditions.

The atmospheric structure vertical data displayed expected characteristics on this day. There was no capping layer evident and very little surface-based thermal activity.

The atmosphere was well mixed to 1000 m (the scope of the Doppler). The temperature profiles and inland acoustic sounder data for this day support these observations.